Chapter 3

AGRONOMICS OF TEFF

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This chapter gives an overview of the agronomics of teff primarily focusing on the major biophysical aspects of the teff plant and its husbandry in Ethiopia. The first section elaborates on the major peculiar features that constitute the reasons for the sustained extensive cultivation of the crop in Ethiopia. An understanding and appreciation of the relative merits of the crop in cultivation and use are vital for government policy makers, researchers, development partners and donors, and the public at large for agrarian transformation in Ethiopia to be achieved. Notably, the focus on research and development of teff has given rise to considerable attention of this crop's significance and meritorious features. In the subsequent sections, other salient aspects are covered, including brief insights into the genetic resources to improve the crop, the improved varieties released so far, and the agronomic and pest management methods used in teff husbandry. The chapter concludes with a summary of the practical implications of the major issues covered, followed by remarks on the prospects of teff research and development in Ethiopia.

Significance of the Teff Crop in Ethiopia

In Ethiopia the cultivation of teff predates historical records, and it existed even before the introduction of wheat and barley in the country. Despite its low productivity (current national average is about 1.3 metric tons per hectare), the Ethiopian farmers who engineered domesticating the crop have continued growing teff over the millennia with its acreage increasing through time. Hence, an important question to consider is, Why have Ethiopian farmers continued growing teff? The teff crop exhibits a multitude of relative merits to both husbandry and use (Ketema 1993; Tefera and Ketema 2001; Assefa 2003; Assefa et al. 2012) as discussed below.

Relative Merits in Husbandry

The major relative merits of teff over the other crops in terms of husbandry include its (1) broad adaptation to a range of altitudes from below sea level up to 3,000 meters above sea level and to varied agroecological and edaphic conditions; (2) reasonable tolerance to both low (drought) and high (waterlogging) moisture stresses; (3) importance as a reliable and low-risk catch crop at times when other crops (such as maize and sorghum) fail due to natural calamities such as drought, pests, and diseases; (4) adaptability to various cropping systems and crop rotation schemes; (5) relative resilience from serious epidemics of pests and diseases in at least the country's major teff production regions; and (6) minimal postharvest losses since the grains suffer less from damage by storage pests (such as weevils) and diseases.

Relative Merits in Use

In addition to its merits in farming, the sustained cultivation of teff is also prompted by its relative merits in terms of its use over other crops. These major relative merits include the following: First, the grains of teff give the best quality and most consumer-preferred injera (traditional fermented Ethiopian pancake) in terms of water-holding capacity, long shelf-life, unique flavor (slightly sour but pleasant), pliability, and smooth and glossy texture. Second, the grains yield high returns in flour upon milling of 99 percent, compared to 60–80 percent from wheat (Ebba 1969). In other words, if 100 kilograms of wheat are used for milling, the usable flour yield is 60–80 percent and the rest is bran, while 100 kilograms of teff gives 99 percent flour yield. Upon baking, teff flour produces a large amount of injera due to its high water-holding capacity. Third, teff entails minimal postharvest losses and high storage longevity of the grains even under traditional storage conditions. Fourth, the straw is important mainly as fodder for cattle and as a binder of mud used for plastering walls of local houses. Fifth, teff offers cash crop value for farmers owing to the high market prices of both the grains and the straw.

Teff is a very nutritious cereal grain. Its nutritional content is generally comparable to that of the major world cereals like wheat, barley, rice, maize, and sorghum (Table 3.1). In fact, teff is superior in many aspects, particularly in such minerals as iron, calcium, magnesium, and zinc. In recent years teff has become popular as a health and performance food in the global market. Since the grains are gluten-free, it is useful as food for humans suffering from the gluten protein allergy ailment known as celiac disease (Spaenij-Dekking, Kooy-Winkelaar, and Koning 2005). Its low glycemic index characterized

TABLE 3.1 Nutritional composition (%) of teff grains compared with other major world cereals

Nutritional item	Teff	Wheat	Rice	Maize	Sorghum	Barley
Protein	11.0	11.0	9.7	9.4	8.6	8.5
Fat	2.6	1.9	1.6	4.4	3.8	1.5
Fiber	3.5	1.9	5.8	2.2	1.9	4.5
Carbohydrates	73.0	69.3	64.7	69.2	71.3	67.4
Mineral ash	3.0	1.7	5.0	1.3	2.4	2.6

Source: Modified from Agren and Gibson (1968).

by slow-release-type starches make it particularly suitable for diabetic people. Moreover, its high iron content is associated with the low prevalence of hook worm (Ethiopian Nutrition Survey 1959) and pregnancy-related anemia in people consuming teff as a staple food. Further details on the nutritional aspects of teff are covered in Chapter 15.

Botany of Teff

Taxonomy

Teff belongs to the Grass Family, Poaceae (formerly Gramineae), subfamily Chloridoide (Eragrostoidae), tribe Eragrostidae, subtribe Eragrosteae, genus *Eragrostis*. As one of the biggest genus in the grass family, the genus *Eragrostis* contains over 350 species (Watson and Dallwitz 1992). Of these species, about 43 percent are considered to have originated in Africa, 18 percent in South America, 12 percent in Asia, 10 percent in Australia, 9 percent in Central America, 6 percent in North America, and 2 percent in Europe (Costanza 1974). Among the 54 species found in Ethiopia, 14 are endemic to the country (Cufodontis 1974). Teff and finger millet (*Eleusine coracana* (L.) Gaertn.) constitute the sole species in the subfamily Chloridoidae cultivated as a cereal crop for human consumption.

Various nomenclatures have been given to teff by several authorities at different times. These synonymous binomial nomenclatures are summarized in Table 3.2. However, the most accepted binomial nomenclature for teff is *Eragrostis tef* (Zucc.) Trotter. In this nomenclature "Zucc." stands for Zuccagni, the taxonomist who gave the species epithet "tef"; "Trotter" stands for the name of the taxonomist who proposed the binomial name *Eragrostis tef* in 1918 based on the species epithet first given by Zuccagni.

TABLE 3.2 Various binomial nomenclatures given to teff by authorities in different years

Suggested name	Year
Poa tef Zuccagni	1775
Poa abyssinica Jacquin	1781
Poa cerealis Salisb	1796
Cynodon abyssinicus (Jacq.) Rasp.	1825
Eragrostis abyssinica (Jacq.) Link	1827
Eragrostis pilosa (L.) P. Beauv. subsp. *abyssinica* (Jacq.) Aschers and Graben	1900
Eragrostis tef (Zucc.) Trotter	1918
Eragrostis pilosa (L.) P. Beauv. var *tef* (Zucc.)	1923

Source: Modified from Ebba (1975) and Ketema (1993).

Genetics

The species in the genus *Eragrostis* generally range from diploid (2x = 2n = 20) to hexaploid (2x = 6x = 60). Teff is an allo-tetraploid species (2n = 4x = 40) originating from the hybridization of two distinct species followed by diploidization. Through cytological examinations the formation of 20 bivalents in the meiotic Metaphase I in both the interspecific and intraspecific hybrids provides evidence of it being an allotetraploid hybrid (Tavassoli 1986). In support of this, other genetic studies further depicted disomic inheritance patterns for some qualitative characters, including panicle form and branching pattern as well as glume/lemma and caryopsis color (Berhe et al. 1989a, 1989b, 1989c).

Although the putative ancestral diploid progenitor species for teff are not fully known, based on morphological and cytological evidences, Ponti (1978) and Tavassoli (1986) suggested that the following species are closely related to teff: *Eragrostis aethopica* (2x), *E. pilosa* (4x), *E. mexicana* (6x), *E. barrelieri* (6x), *E. minor* (2x, 4x), and *E. cilianensis* (2x, 4x, 6x). Recent DNA-based studies (Ayele 1999; Ayele et al. 1999; Ayele and Nguyen 2000; Bai et al. 1999, 2000; Ingram and Doyle 2003) confirmed that *E. pilosa* is the closest relative and presumably one of the intermediate wild progenitors of teff.

As revealed from the karyotype analyses of 15 *Eragrostis* species, the chromosomes of teff are minute even by the standards of the genus, with the largest and smallest chromosomes of teff measuring from 1.6–2.9 and 0.8–1.1 micrometers (μm) respectively. The range in each of these two size groups is due to differences in condensation (Tavassoli 1986). This implies that the largest chromosome of teff is approximately three times smaller than the smallest (1D) wheat chromosome (Gugsa, Belay, and Ketema 2001). Unlike that of some of its related wild *Eragrostis* species, the presence of chromosomal races and aneuploidy is not known in teff.[1] Indeed, flow cytometric analysis revealed that the tetraploid nuclear genome size of teff is about 730 megabase pair (Mbp), and no significant teff genotype differences were noted (Ayele et al. 1996; Hundera, Arumuganathan, and Baenziger 2000). This indicates that the genome size of teff is roughly 50 percent larger than the rice genome, and the equivalent diploid teff genome size is about 75 percent the size of the rice genome (Kantety et al. 2001). Notably, two of the three major world cereals (wheat, rice, and maize) are large genome size polyploids, with wheat being an allopolyploid (6x = 16,000 Mbp) and maize being an ancient tetraploid (4x, 2,500 Mbp).

Morphology and Physiology

Teff plants rarely root from nodes above the base, with the roots growing 4–8 centimeters deep in a very thin, fibrous (threadlike) root system under field conditions (Ebba 1975). Generally, teff plants grow to 20–156 centimeters high, of which the culm or stem (11–82 centimeters) and the panicle (10–65 centimeters) comprise 47–65 percent and 35–53 percent, respectively (Assefa et al. 2001). The stems are mostly erect, rarely creeping or bending or elbowing (geniculate) in few cultivars. They are jointed with hollow internodes separated by nodes. The culm internodes normally increase in length and decrease in thickness toward the tip (acropetal), often being short and thick at the basal part and long and thin at the uppermost internodes.

The teff leaves consist of a basal light green to dark purple sheath distinctly shorter than the corresponding culm internode, a very short and ciliated ligule and a blade or lamina. The latter are slender, narrow, flat, and nearly linear or linear-lanceolate with elongated acute tips. The blades vary in color and in size, generally measuring 2–55 centimeters long and 2–10 millimeters wide at the broadest part (Ebba 1975).

The inflorescence of teff is paniculate, which varies in form from very compact with the panicle branches appearing fused to the rachis forming a whiplike structure to very loose types of open and laterally spread branches. The color of the lemmas, which is important in the classification of teff cultivars, can be grayish olive, yellow green, green, dark purple, dark red, grayish yellow

1 Aneuploidy is a form of polyploidy where certain chromosomes are duplicated as opposed to the duplication of the whole chromosome set.

green, or variegated with red or purple tips and margins of yellow green, greenish yellow, grayish olive, or green basal color backgrounds. In these variegated cultivars, the mix of colors is not all over the lemmas but rather across the tips and the margins. The seed are very small (100 kernel mass = 10–38 milligrams), generally ovoid or oblong to ellipsoidal, and opaque or lustrous, and their embryo marks facing the lemmas are about five-sevenths the size of the grain. The grains range in color from dark brown to orange white (Ebba 1975).

Teff generally takes 25–81 days to emerge the panicle tips, 60–140 days to mature, and 29–76 days for the grain filling period (Assefa et al. 2001). It is a C4 plant having Kranz-type leaf anatomy with the vascular bundles surrounded in a circular manner bundle, with sheath cells consisting of high concentrations of chloroplasts, and depicting low CO_2 compensation of leaves, which is typical of C4 as opposed to C3 species (Kebede, Johnson, and Ferris 1989).

Breeding

Historical Milestones

Scientific research in teff improvement started in the late 1950s at the former Jimma Technical and Agricultural High School, as it was known, in Jimma. The research was moved in 1960 to the then Central Experiment Station, now the Debre Zeit Agricultural Research Center. With regard to the overall history of teff breeding, the following three interrelated phases are distinguished:

- Phase I (1956–1974) was characterized by: (1) germplasm enhancement (collection/acquisition, characterization and evaluation, systematics and conservation); (2) genetic improvement relying entirely on mass and/or pure-line selection directly from the existing germplasm; and (3) initiation of induced mutation techniques.
- Phase II (1975–1995) featured: (1) the discovery of the chasmogamous floral opening behavior of teff flowers (from about 6:45–7:30 am) and thereby the artificial crossing technique by Berhe (1975); and (2) incorporation of intraspecific hybridization in the genetic improvement program following the discovery of the crossing technique.
- Phase III (1995–to date) is characterized by: (1) initiation of molecular/genomics approaches involving development of molecular markers and

genetic linkage maps and analyses of molecular genetic diversity; (2) incorporation of in vitro culture techniques and interspecific hybridization; (3) reappraisal of induced mutagenesis particularly for lodging and leaf rust disease resistance; and (4) strengthened use of participatory breeding approaches (Belay et al. 2006; Belay et al. 2008).

Objectives of the Teff Breeding Program

The overall objectives of the teff breeding program are the following: (1) to enrich and improve the germplasm resource base; (2) to develop suitable varieties for different agroecologies and cropping systems; and (3) to generate basic scientific information on the crop species. To reach these objectives, attention has focused on the following: (1) high productivity in terms of both grain and straw yield; (2) tolerance to low moisture stress; (3) improved lodging resistance; and (4) desirable grain quality mainly in terms of most farmer and consumer-preferred caryopsis color (often white).

Breeding Methodology

Figure 3.1 illustrates the process of the teff breeding methodology. The first step generally involves germplasm enhancement through mainly collection/acquisition, characterization and evaluation, hybridization (intraspecific and interspecific) and induced mutation techniques.

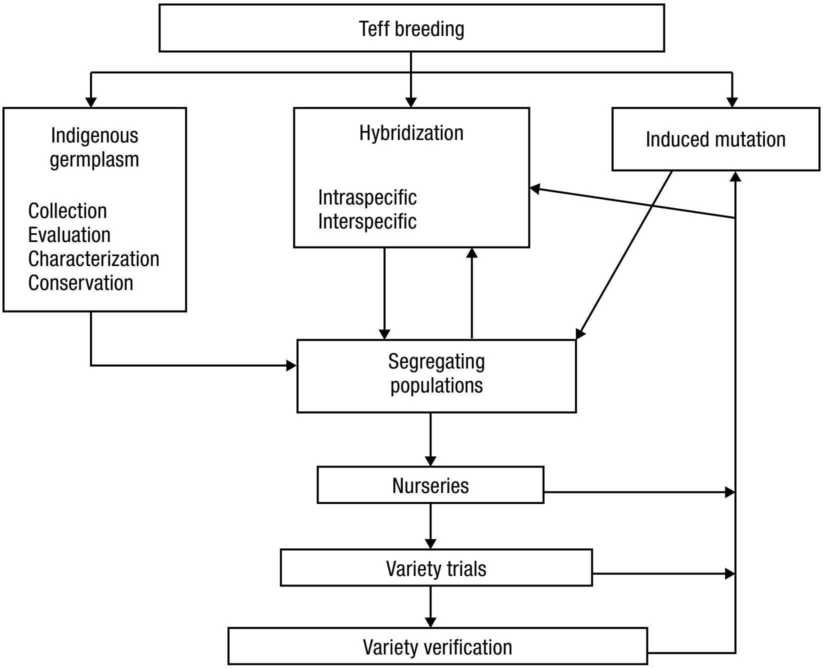
Ethiopia is the center of both origin and diversity of teff (Vavilov 1951). In the absence of influences from abroad regarding breeding materials, the crop's genetic improvement relies heavily on the indigenous genetic resources. Table 3.3 summarizes current holdings of teff germplasm accession in the world. The Ethiopian genebank at the Ethiopian Biodiversity Institute alone presently holds a total of 5,169 accessions.

Following the germplasm enhancement are generation advancement and handling of segregating populations from crossing and induced mutation, observation nurseries, series of field variety trials, and ultimately variety verification trial for release. For handling such segregating populations, the breeding methods adopted are mainly modified pedigree and bulk methods; in some cases also single-seed descent methods are used (Poehlman and Davis 1995).

Breeding Strategies and Institutional Setup

When considering the vast acreage devoted to teff production in Ethiopia, and the level of investment in teff improvement research in general, the overall teff

FIGURE 3.1 Teff variety development process



Source: Assefa et al. (2011); Assefa, Chanyalew, and Metaferia (2013a).

breeding philosophy is centered on "add a little, and it makes a difference." In other words, even if the improvement in productivity is very little, this would have a significant practical impact when multiplied by the total acreage of teff in Ethiopia. With this considered, the major strategies of the current teff breeding focus include (1) shift from wide to specific adaptation due mainly to high genotype × environment interaction while still looking for broad adaptation; (2) market orientation with respect to quality, quantity, and food security; and (3) expansion to nonconventional (new) growing areas.

The institutional setup for teff improvement in Ethiopia involves the National Agricultural Research System (NARS). The Debre Zeit Agricultural Research Center (DZARC) of the Ethiopian Institute of Agricultural Research (EIAR) forms part of the NARS and is the center of excellence for teff research. It has primary responsibilities for national coordination of the overall research endeavors, and the development and execution of country-wide teff research projects. The implementation of the research involves three institutions: (1) the Federal Research Centers of EIAR (Debre Zeit and its

TABLE 3.3 Teff germplasm accessions in gene banks in different parts of the world

Source and Institution	Number of samples and accessions
Ethiopia, Ethiopian Biodiversity Institute	5,169
Germany, Institute of Crop Science, Braunschweig	30
Germany, Institute for Plant Genetics and Crop Plant Research (IPK)–Genebank, Gatersleben	5
Japan, Department of Genetic Resources, International Institute of Agrobiological Resources	30
Yemen, Agricultural Research and Extension Authority	2
Russia, N.I. Vavilov All-Russian Research Institute of Plant Industry, Saint Petersburg	14
Slovak Republic, Botanical Garden of the University of Agriculture	1
South Africa, Division of Plant and Seed Control, Department of Agriculture and Technology Service, Private Bag X179, Pretoria	3
UK, Welsh Plant Breeding Station, Institute of Grassland and Environment Research	3
US, National Seed Storage Laboratory, USDA-ARS, Colorado State University, Fort Collins, Colorado	341
US, Western Region Plant Introduction Station, USDA-ARS, Washington State University, Pullman	368
Total	**5,966**

Source: Updated from Ketema (1997) and Tesema (2013).

subcenters Ambo, Assosa, Holetta, Melkassa, and Pawe); (2) centers of the Regional Agricultural Research Institutes (RARIs) such as Adet, Alamata, Areka, Axum, Bako, Mekelle, Sekota, Sinana, Sirinka; and (3) Haramaya University from the higher learning institutes (HLIs). In addition, on-farm trials are carried out on farmers' fields in different parts of the country through the various centers involved in teff research.

Achievements (Improved Teff Varieties)

To date, a total of 33 varieties have been released in Ethiopia through the National Agricultural Research System (Ethiopia, MoA 2013) (Table 3.4). Of these, 19 varieties have been released by Debre Zeit Agricultural Research Center. The remaining 14 teff varieties released were 2 by Holetta, 1 each by Melkassa and Areka, 5 by Sirinka, 3 by Adet, and 2 by Bako agricultural research centers. Of the total number of released varieties, 10 varieties were developed through hybridization, and of these, 9 were released by Debre Zeit Agricultural Research Center.

Four of the released varieties, viz. Magna (DZ-01-196), Enatite (DZ-01-354), Dukem (DZ-01-974), and Quncho (DZ-Cr-387 RIL355) are widely

TABLE 3.4 List of improved teff varieties released by Debre Zeit Agricultural Research Center, 1970–2010

Variety name	Common name	Year of release	Days to mature	Plant height (centimeters)	Seed color	Grain yield (t ha-1)	
						On-station	On-farm
A. Varieties Released by Debre Zeit Agricultural Research Center							
DZ-01-99	Asgori	1970	80–130	53–100	Brown	2.2–2.8	1.8–2.2
DZ-01-354	Enatit	1970	85–100	53–115	Pale white	2.4–3.2	2.0–2.4
DZ-01-196	Magna	1970	80–113	50–117	Very white	1.8–2.4	1.6–2.0
DZ-01–787	Wellenkomi	1978	90–130	50–110	Pale white	2.4–3.0	2.0–2.4
DZ-Cr-44	Menagesha	1982	95–140	85–110	White	1.8–2.4	1.8–2.2
DZ-Cr-82	Melko	1982	112–119	96–112	White	1.8–2.4	1.6–2.0
DZ-Cr-37	Tsedey	1984	82–90	67–92	White	1.8–2.5	1.4–2.2
DZ-Cr-255	Gibe	1993	114–126	63–116	White	2.0–2.6	1.6–2.2
DZ-Cr-358	Ziquala	1995	76–138	84–132	White	2.4–3.4	2.0–2.7
DZ-01-974	Dukem	1995	75–137	70–109	White	2.4–3.4	2.0–2.7
DZ-01-1281	Gerado	2002	73–95	83–100	White	1.7–2.4	1.6–2.2
DZ-01-1285	Koye	2002	104–118	80–92	White	1.7–2.4	1.6–2.2
DZ-01-1681	Key Tena	2002	84–93	74–85	Brown	1.7–2.4	1.6–2.2
DZ-01-899	Gimbichu	2005	118–137	46–68	Pale white	1.5–2.2	1.6–2.0
DZ-01-2675	Dega Tef	2005	112–123	47–91	Pale white	1.5–2.4	1.4–2.2
DZ-Cr-387 RIL355	Quncho	2006	86–151	72–104	Very white	2.0–3.2	1.8–2.6
Ho-Cr-136	Amarach	2006	63–87	67–81	Pale white	1.8–2.5	1.4–2.2
DZ-Cr-285 RIL295	Simada	2009	75–87	65–80	White	2.0–2.8	1.6–2.4
DZ-Cr-409 RIL 50d	Boset	2012	75–86	75–90	Very white	1.9–2.6	1.8–2.4
B. Varieties released by Holetta Agricultural Research Center							
DZ-01-2053	Holetta Key	1998/ 1999	84–112	78–112	Brown	1.7–2.4	1.5–2.2
DZ-01-1278	Ambo Toke	1999/ 2000	86–116	75–112	Brown	1.7–2.4	1.5–2.2
C. Varieties released by Melkassa Agricultural Research Center							
DZ-Cr-387 RIL127	Gemechis	2007	67–90	72–95	Very white	1.5–2.0	1.6–1.8
D. Varieties Released by Adet Agricultural Research Center							
DZ-01-1868	Yilmana	2005	98–110	89–120	Pale white	1.8–2.4	1.7–2.0
DZ-01-2423	Dima	2005	92–106	85–115	Brown	1.7–2.3	1.6–2.1
DZ-01-3186	Etsub	2008	95–105	87–112	White	1.9–2.4	1.9–2.4
E. Varieties released by Bako Agricultural Research Center							
DZ-01-1880	Guduru	2006	95–120		White	1.8–2.2	1.6–2.0
23-Tafi-Adi-72	Kena	2008	98–124		White	1.8–2.4	1.7–2.2

Variety name	Common name	Year of release	Days to mature	Plant height (centimeters)	Seed color	Grain yield (t ha-1)	
						On-station	On-farm
F. Varieties released by Sirinka Agricultural Research Center							
DZ-01-2054	Gola	2003	82–90	65–98	Pale white	1.4–1.9	1.2–1.6
DZ-01-146	Genete	2005	75–87	67–98	Pale white	1.4–2.0	1.2–1.6
DZ-01-1821	Zobel	2005	72–87	65–95	Pale white	1.4–2.0	1.3–1.8
Acc. 205953	Mechare	2007	78–85	62–92	Pale white	1.5–2.1	1.4–1.8
DZ-CR-387 RIL273	Laketch	2009	87–92	78–95	Very white	1.7–2.2	1.8–2.0
G. Varieties released by Areka Agricultural Research Center							
PGRC/E 205396	Ajora	2004	89–96	89–98	Pale white	1.4–2.0	1.6–1.8

Source: Modified from Assefa, Chanyalew, and Metaferia (2013a).

adopted by farmers in areas with optimum rainfall in different parts of the country, while the relatively early maturing varieties of Tsedey (DZ-Cr-37), Gemechis (DZ-Cr-387 RIL127), Simada (DZ-Cr-285 RIL295), and Boset (DZ-Cr-409 RIL50d) are recommended for terminal low moisture stress areas.

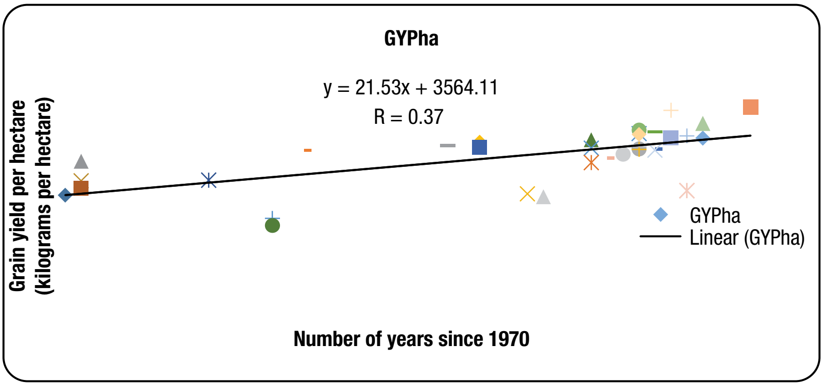
Genetic Gain

Recent studies of the breeding progress in terms of genetic gain using evaluation of the 33 teff varieties released in Ethiopia since 1970 till now at Debre Zeit and Melkassa Agricultural Research Centers showed that grain yield increased from 3093.8 kilograms per hectare to 4934.4 kilograms per hectare over the past 42 years (Figure 3.2) (Dargo 2013).[2] The average annual rate of increase from 1970–2012 as estimated from the slope of the graph of the linear regression of mean grain yield on year of variety release was 21.53 kilograms per hectare with a relative genetic gain of 0.56 percent per year. Biomass yield (Figure 3.3) and grain yield per panicle also showed significant increase with respective annual genetic gains of 0.47 percent and 1.05 percent.

The linear regression indicates significant improvements in biomass production rate and grain yield per day. No marked changes were observed in phenologic traits, harvest index, plant height, panicle length, panicle weight, lodging index, and hundred seed weight during the study period. This implied that teff varieties have failed to bring substantial progress or improvements on

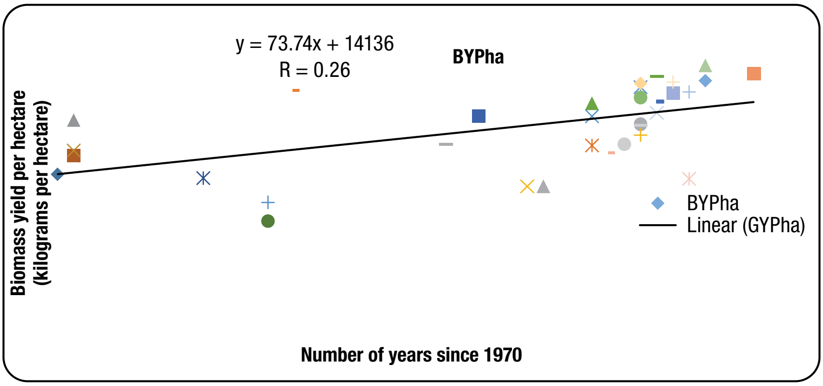
2 With varieties, the productivity difference is due to genetic manipulation, and hence genetic gain is used to describe the changes in productivity over time due to the genetic manipulations.

FIGURE 3.2 Relationship between mean grain yield of 33 teff varieties and year of release, expressed as number of years since 1970



Source: Dargo (2013).
Note: GYPha = grain yield per hectare.

FIGURE 3.3 Relationship between mean biomass yield of 33 teff varieties and year of release, expressed as number of years since 1970



Source: Dargo (2013).
Note: BYPha = biomass yield per hectare.

these mentioned traits through the breeding efforts made over the specified years. Stepwise regression analysis revealed that most of the variation in grain yield of teff was caused by biomass yield and harvest index.

Overall, the genetic gain study revealed that the grain yield potential of teff has not reached a plateau in Ethiopia. Development of higher yielding varieties should thus continue to increase teff grain yields if past trends are indicative of the future. To see the impact in the genetic progress research of teff, it is imperative to undertake large-scale popularization of the released varieties, where the end user farmers can see the impact of such improved varieties through demonstrations and scaling-up activities, such as improved management practices.

Success Stories with the Quncho Teff Variety and Related Innovations

Before the release of the Quncho teff variety, a number of improved varieties were developed and released by the national agricultural research system. Nonetheless, the improved varieties have not been widely adopted by farmers to bring about any discernible impacts on the production and productivity of teff in Ethiopia. The slow and low rate of adoption of the improved varieties is because, among other reasons, farmers preferred the qualities of their local varieties and claimed that the improved varieties were not superior. However, the development and release of the popular Quncho teff variety in 2006 marked a breakthrough achievement in the overall development, dissemination, and adoption of improved teff technologies. This success story can be attributed to some major innovative approaches (Assefa et al. 2011; Assefa, Chanyalew, and Metaferia 2013b) as described below.

Development of the Variety

Before starting the breeding work for the development of the Quncho variety, the first step undertaken was participatory variety selection (PVS) and participatory plant breeding (PPB) to identify the varieties preferred by farmers and traits therein (Belay et al. 2006; Belay et al. 2008). The major outcomes of these studies, in addition to the yield of both grain and straw, was the overriding preferred trait of a white seed color by farmers and consumers alike. Based on this, targeted crossing was undertaken between two selected teff varieties that had been formally released to combine high yield and the farmers' and consumers' preferences.

The teff variety Quncho with the pedigree of [(974 × 196)-HT′-387 (RIL355)] was developed from the cross made by Debre Zeit Agricultural Research Center in 2000. The parental varieties DZ-01-196 (Magna) and DZ-01-974 (Dukem) are old improved varieties developed through pure-line selection and released in 1970 and 1995 respectively (Tefera and Assefa 1995; Tefera et al. 2001). The maternal (ovule) parent DZ-01-974 (Dukem) is a high-yielding variety, although farmers did not prefer this variety because

TABLE 3.5 Performance and characteristics of Quncho as compared with the parental lines and the local variety

Traits	DZ-01-974 (Dukem)	DZ-01-196 (Magna)	Quncho	Local variety
Panicle form	Very loose	Fairly loose	Very loose	Mixture
Lemma color	Yellowish-green	Yellowish-green variegated with red	Yellowish-green variegated with red	Mixture
Seed color	Pale white	Very white	Very white	Mixture
Plant height (centimeters)	107	97	102	103
Days to mature	107	97	105	118
On-station grain yield (metric tons per hectare)	2.4–3.4	1.8–2.2	2.2–2.8	1.8–2.2
On-farm grain yield (metric tons per hectare)	2.0–2.5	1.4–1.6	1.8–2.2	1.2–2.0
On-station straw yield (metric tons per hectare)	12	9.6	10.11	10.09
On-farm straw yield (metric tons per hectare)	10.00	8.10	9.10	6.18

Source: Assefa et al. (2012); Assefa, Chanyalew, and Metaferia (2013b).

of its pale white seed color fetching a low market price. The male (pollen) parent DZ-01-196 (Magna) possesses the popular very white seed color, although its productivity has been relatively low (1.6–1.8 metric tons per hectare). Subsequently, a targeted cross was made between the two varieties, with the objective of selecting recombinants combining the high yield of DZ-01-974 (Dukem) and the seed quality trait of DZ-01-196 (Magna). Rapid generation advancement up to three generations per year was made using off-season irrigation facilities.[3] Eventually, Quncho was developed as a Recombinant Inbred Line (RIL) through an F2-derived single-seed descent method. Following a series of multi-environment yield tests in various major teff-growing regions of the country, it was officially released in 2006.

The performance and distinguishing features of the teff variety Quncho, as compared with the parental and the farmers' (local) varieties, are summarized in Table 3.5. The new variety has inherited its very white seed color and also the lemma color (yellowish-green variegated with red tips and margins) from the pollen parent DZ-01-196 (Magna). It has taken its high-yield potential and panicle form (very loose) from the ovule parent DZ-01-974 (Dukem).

3 After crossing, an F1 is obtained. This has then to go through generation advancement as F2, F3, F4, and so on until homozygous lines are obtained.

Variety Branding

The variety branding by naming it Quncho has played a significant role, particularly in the popularization and promotion of the variety. The name Quncho in most Ethiopian vernaculars means "top brass," "at the helm," or "topmost."

Intensification of Seed Multiplication

To accelerate the supply of quality seeds of the Quncho variety to the ultimate users, an intensified seed multiplication scheme was followed. This new innovative and accelerated seed multiplication involved the following:

- Enhancing seed multiplication of research centers both during the off-season using irrigation facilities and during the main season.
- Enhancing on-farm seed production by strengthening the capacities of farmers through the provision of initial seeds, training, and technical support.

By using on-farm seed production, the indigenous knowledge in teff seed production and maintenance were more effectively exploited. Consequently, better quality teff seeds can be produced through such informal means, provided that the farmers are given technical support. In this respect, clustering of adjacent fields has proven effective in minimizing seed contamination and enabling the production of good quality seeds. In addition, private seed growers have been encouraged to produce teff seeds, especially that of the Quncho teff variety.

Multistakeholder Partnership Extension Approach

A new approach to demonstrate, popularize, and disseminate the Quncho teff technology was adopted. It was characterized by the following major features:

- Dissemination of technology as a package: Unlike the previous "piece-meal" approach with a single technology, the dissemination approach involved "technology as a package" with the Quncho teff variety used as the vehicle along with other associated improved management practices.[4]

4 In the improved technology package, the variety forms the central part but the package also includes improved practices involving the use of fertilizers, appropriate land preparation, time of sowing, seed rate, weed control, management of other pests, timely harvesting, and the like.

- Use of large farmers' fields: Instead of the formerly used small (10 × 10 meter) plots, large field plots of one-fourth of a hectare were used in in-farm demonstrations and scaling up of the Quncho teff technology.
- Coordination of multistakeholders' partners: These include research centers, extension agents, farmers, NGOs, farmers' associations such as farmers' cooperatives and cooperatives' unions, district administration offices, and other institutions involved in rural development.
- Revolving seed loan: In the scaling up of the technology, seeds of the variety Quncho were distributed to participating farmers on a "revolving-seed-loan" basis such that the farmers would return the same amount of seed after harvest.
- Provision of regular training: Regular training of farmers, development agents, and extension personnel on the technologies contributed immensely to the success of the demonstration and scaling up of the technology on the farmers' fields.
- Regular follow-up and supervision: In addition to training, regular input by a team of researchers and extension agents also played an important role in the rapid and effective dissemination of the technology.
- Provision of inputs and marketing options: Insofar as possible, provisions were made in terms of inputs and options for marketing of produce mainly by involving farmers' cooperatives and cooperatives' unions in the supply of such inputs as fertilizers and purchases of the produce.

As a consequence of the new extension approaches practiced since the release of the Quncho teff variety in 2006, a total of over 41,655 teff-producing farmers' households with a total area of more than 12,850 hectares directly participated in the scaling-up activities carried out through the partner research centers and the National Crop Technology Scaling-up Program (Table 3.6). This venture involved the distribution of about 385 metric tons of seed of the Quncho variety with the average yield obtained by the farmers ranging from 2.0 to 2.3 metric tons per hectare. At this juncture it is important to note that these figures do not include the dissemination of the variety made through other channels, such as horizontal farmer–farmer seed exchange and through the formal extension system of the offices of agriculture.

Recent adoption and impact assessment studies of improved teff technologies in three woredas (Minjar Shenkora, Ada, and Lume) in the central

TABLE 3.6 Summary of direct dissemination of the Quncho teff variety through center-level and national scaling-up activities, 2006–2013

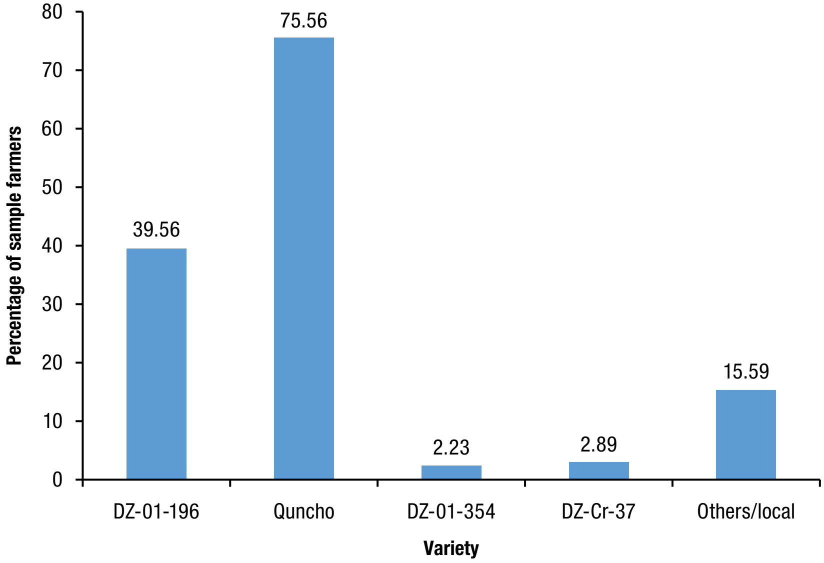
Year	Number of farmers' households participated	Farm area covered (hectares)	Amount of seed distributed (metric tons)	Total grain yield (metric tons)	Average grain yield (metric tons ha^{-1})
2006	300	150	4.50	300.00	2.0
2007	506	253	7.59	556.60	2.2
2008	1,060	530	15.90	1,166.00	2.2
2009	5,875	2,938	88.14	6,464.00	2.2
2010	10,113	3,029	90.87	6,967.00	2.3
2011	13,157	3,292	98.76	7,571.60	2.3
2012	9,332	2,333	69.99	5,365.90	2.3
2013	1,312	328	9.84	—	—
Total	**41,655**	**12,853**	**385.59**	—	—

Source: Assefa, Chanyalew, and Metaferia (2013b).
Note: — = data not available.

highlands of Ethiopia revealed that Quncho is reported to be the most widely adopted improved variety, followed by DZ-01-196 (Magna). Within the study area, the study showed the Quncho variety was adopted by 76 percent of the farmers while Magna was adopted by 40 percent of the respondent farmers (Figure 3.4). By comparing this result with that of a similar survey conducted in the same area during the cropping season in 2008/2009, the adoption of Quncho far exceeded expectation. For instance, its adoption rate increased from 5 percent in 2008/2009 to 76 percent in the 2011/2012 cropping season. On the contrary, the adoption rate of DZ-01-196 (Magna) dropped from 84 percent in 2008/2009 to 40 percent in 2011/2012.

In terms of intensity of adoption, which is measured by the proportion of total teff area allocated to a particular variety, Quncho comes first by covering 66 percent while DZ-01-196 (Magna) accounted for 26 percent of the total teff acreage (Figure 3.5). Similar to that of the adoption rate, the intensity of adoption for Quncho has increased from 4 percent in the 2008/2009 cropping season to 66 percent in 2011/2012. On the contrary, the adoption intensity of DZ-01-196 (Magna) has dropped from 71 percent to 26 percent in the respective cropping seasons. Figure 3.5 clearly indicates how the share of local varieties has diminished to just 5 percent.

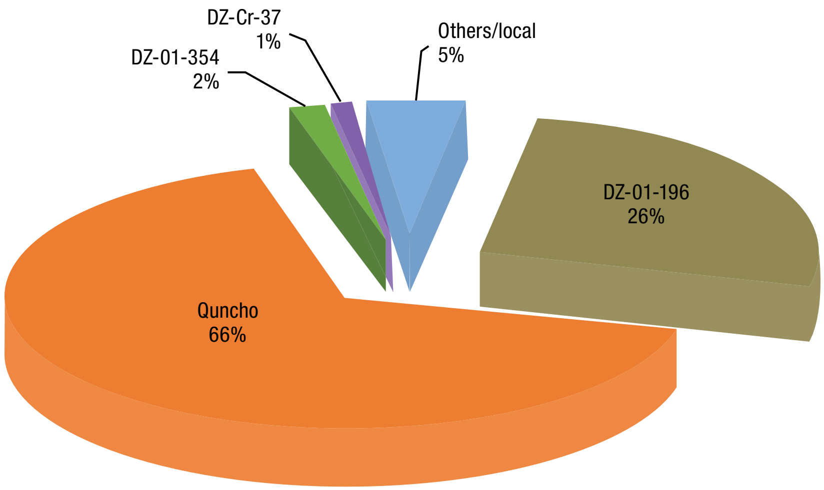
FIGURE 3.4 Adoption of improved teff varieties, 2011/2012 cropping season



Source: Survey data, 2012.

Note: Percentages are based on multiple responses.

FIGURE 3.5 Intensity of adoption of improved teff varieties measured by the proportion of teff area covered with improved varieties, 2011/2012 cropping season



Source: Survey data, 2012.

Challenges and Opportunities

Challenges

The major challenges in teff breeding in particular, and the overall teff improvement in general, include the following:

- Lack of attention: Teff can be categorized as an orphan or a neglected crop because of its localized solitary importance in Ethiopia. Consequently, it has lacked the attention of the global scientific community as well as that of donors and has therefore remained underresearched. Unlike that of the other major world crops, no CGIAR centers or regional institutions have been established to deal with the improvement of localized crops like teff. Furthermore, the national focus has remained very limited. Even though there have been trends for improvement in crop development, teff has for a long time been omitted from Ethiopia's national research and development priority commodities, seemingly not corresponding to the actual significance of the crop in Ethiopia.
- Technical and scientific challenges: Teff improvement suffers due to a lack of studied information on the species, low productivity, the unresolved malady of lodging in teff, and the tiny seeds that render its husbandry very demanding.
- Capacity and institutional limitations: Currently, Debre Zeit Agricultural Research Center is assigned to be the "Center of Excellence" (CoE) for teff research in Ethiopia. However, there has been limited capacity both at the CoE and national level at large in terms of trained and skilled human resources, infrastructure, facilities, and financial budget. Besides, mechanisms for coordinated efforts in teff research at a countrywide level have not yet been developed.

Opportunities

Despite the challenges that require commensurate attention, there have been ample opportunities for the improvement of teff.

AVAILABILITY OF DIVERSE WEALTH OF GENETIC RESOURCES

The teff genetic resources harbor a tremendous diversity in phenologic, agronomic, and morphologic traits (Table 3.7), coupled with unexploited aspects in terms of nutritional as well as biotic and abiotic stress-tolerance traits. The wealth of diversity in the species offers ample opportunities for genetic

TABLE 3.7 Ranges of some important traits of teff

Trait	Minimum	Maximum
Days to panicle emergence	25	81
Days to mature	60	140
Grain filling period (days)	29	75
Plant height (centimeters)	20	156
Culm length (centimeters)	11	82
First culm internode length (centimeters)	2.68	8.05
Second culm internode length (centimeters)	4.15	11.45
First and second culm internode diameter (centimeters)	1.2	4.5
Panicle length (centimeters)	10	65
Peduncle length (centimeters)	5.85	42.3
Number of primary panicle branches	10	40
Number of spikelet per panicle	30	1070
Number of florets per spikelet	3	17
Grain yield per panicle (grams)	0.11	2.5
Number of tillers per plant (total)	4	22
Number of tillers per plant (fertile)	1	17
Grain yield per plant (grams)	0.54	21.9
Total phytomass per plant (grams)	4	105
Hundred kernel mass (milligrams)	18.97	33.88
Grain yield (kilograms per hectare)	1,058	4,599
Shoot phytomass yield (kilograms per hectare)	6,355	19,630
Diameter of grains (millimeters)	0.50	1.0
Harvest index (%)	5	39
Lodging index	20	100

Source: Modified from Assefa et al. (2001) and Chanyalew, Assefa, and Metaferia (2013).

improvement of the crop and to develop varieties suitable for different agro-ecologies, cropping systems, and purposes.

NEW INSIGHTS IN BREEDING AND OVERALL RESEARCH APPROACHES

The developments in agricultural sciences have opened new insights into how to tackle technical improvements by employing coordinated multifaceted strategies involving conventional breeding; modern techniques including genomics and in vitro cultures; crop, soil, and water management; food science; and mechanization. With respect to breeding in particular, the strategies to be employed involve participatory research approaches, germplasm collection/acquisition, intensification of the hybridization program through increasing the number of crosses, use of intraspecific and interspecific crossing, harnessing potentials of wide crosses (divergent crossing), and targeted crossing (that is, ideo-type crossing for lodging resistance and semi-dwarf types with reduced length of peduncles and basal culm internodes, and thick basal culm internodes).

Likewise, modern biotechnological approaches—such as in vitro culture techniques (especially DH production), molecular markers and linkage maps, QTL analysis, comparative genomics (association mapping), Targeted Induced Local Lesions IN Genomes (TILLING and ECO-TILLING), genome sequence and annotation (functional genomics), MAS, genetic transformation, and harnessing important teff genes—offer new avenues for hastening the genetic improvement of the crop.[5] Furthermore, the productivity and production of teff can be enhanced by the integration of improved management, crop protection, and farm implements and machinery. These value-added practices would be useful to enhance the utilization of the crop. Overall, the broadening of research and development endeavors in these various aspects would open further opportunities.

BRIGHTER PROSPECTS TO IMPROVE TEFF RESEARCH AND DEVELOPMENT

The long-standing belief that teff is not amenable to improvement is now redundant. For the first time in history, the Ethiopian government has realized that transformation of the Ethiopian agriculture is impossible without considering its important local crops, most notably teff. The first thing to be aligned is the national recognition of teff in the priority agricultural commodities. Tied in with the improved national attention to teff, other areas are entailed, including the development and release of the teff value-chain strategy, initiation of focus on the national teff research capability, and improvements in the seed and extension system. In addition, there has been improved international attention especially by donors—namely the McKnight Foundation Collaborative Crop Research Program—that has provided

5 TILLING and ECO-TILLING differ. TILLING involves artificial induction of mutation using mutagenic agents, preferably such chemicals as ethylmethane sulfonate (EMS), and then identifying the induced mutation (local lesion) using molecular methods. In contrast, ECO-TILLING does not involve artificial induction of mutation. It just deals with locating or identifying naturally occurring (spontaneous) mutations using molecular methods just as in the case of TILLING.

sustainable support to the national teff research project since the mid-1990s with commendable achievements.

Apart from the need for enhanced national support, the painstaking ventures of teff improvement generally require enhanced external inputs and support in terms of collaboration, technical and knowledge support, financing, and facilities. Furthermore, the increasing global interests in teff in recent years due to its gluten-free nature, status as a health and performance food, and noble stress-tolerance traits (such as drought resistance) promote attention, particularly in light of climate change.

Agronomy of Teff

Land Preparation

The minute size of teff seeds requires a very fine, flat, and smooth seedbed (Ebba 1969). Conventionally, farmers plow their teff field two to five times before sowing the seeds, depending on the soil type and weed infestation conditions. The traditional plow is called a *maresha*. It is largely used with oxen for the tillage operations, although horses or donkeys are used rarely. Despite the conventional practice, it has recently been shown that teff can be grown with reduced tillage involving pre-emergency application of Roundup at 2 liters per hectare two weeks before sowing, then practicing tillage only once at the time of sowing. Farmers in some areas also practice packing of the seedbeds before sowing using trampling with animals in the anticipation of facilitating good contact of seeds with the soil, avoiding and reducing weed infestation. However, experimental results at Debre Zeit showed that apart from facilitating germination and early stand establishment, packing did not significantly increase yields (DZARC 1989).

Planting

Conventionally, farmers sow teff by hand, broadcasting the seeds on the surface of the soil. Experimental results have indicated that sowing in rows, while it might increase productivity, has the agronomic advantages of easing up subsequent cultural operations such as weed control and harvesting and facilitating efficient use of fertilizers through application as row-side bands. However, for practical use by farmers there has to be a user-friendly solution, such as the development of appropriate smallholder row-sowing implements. Against the conventional farmers' practice of using 40–55 kilograms per hectare, the recommended seed rate with the hand broadcasting method has been

25–30 kilograms per hectare. However, the seed rate can be reduced to 7–10 kilograms per hectare provided that there are mechanisms (implements) that make it feasible for the farmers to use such reduced seed rates. Generally, teff is sown after a sufficient lapse of the onset of the rainy season to ensure the soils are sufficiently wet. The sowing time varies depending on the location, soil type, and prevailing weather conditions. For the central highland areas such as Debre Zeit, the recommended sowing time for teff is the second and the third week of July for light and black clay (vertisols) soils, respectively (Ketema 1993; Hundera, Arumuganathan, and Baenziger 2000).

Fertilizer Application

The recommended fertilizer rates for teff grown on different soil types ranges for nitrogen fertilizer from 40 kilograms per hectare nitrogen for red soils and Nitosols to 75 kilograms per hectare nitrogen for grey soils and black soils, while for phosphorus, it ranges from 50 to 60 kilograms per hectare P2O5 for the different soil types (NFIU 1993). However, the blanket fertilizer recommendation for teff for the major teff-growing areas has been 60 kilograms per hectare nitrogen and 26 kilograms per hectare P2O5 for heavy clay soils (predominantly Vertisols) and 40 kilograms per hectare nitrogen and 26 kilograms per hectare P2O5 for light soils. Commercial fertilizers in Ethiopia have so far been applied in the form of DAP (18 percent nitrogen and 46 percent P2O5) and urea (46 percent nitrogen), and accordingly the blanket recommendation mentioned above, especially for the clay soils, has for practical purposes from the size of the packaging (the least package being 50 kilograms per hectare) been approximated to 100 kilograms per hectare DAP and 100 kilograms per hectare urea.

The amount of fertilizers for teff grown on fields that have been previously used for legumes such as chickpeas can be reduced by half. Moreover, it is recommended that the DAP fertilizer is applied at the time of sowing, while the urea for supplying the remaining of the recommended nitrogen rate should be applied at about the tillering stage (four to five weeks after emergence) of the crops (Mamo, Erkossa, and Tulema 2001; Erkossa 2003).

Harvesting and Threshing

Harvesting of teff is accomplished by farmers mowing with sickles when the crops are mature and dry. The harvested crops are first piled up in the field and later transported by humans and/or using donkeys to the threshing ground areas where they are again piled into bigger piles. After preparing the threshing ground, often by coating with a thin layer of cattle dung, the crops are threshed by trampling with oxen. Winnowing to separate the seeds with the help of wind and subsequent cleaning are done manually with the use of various traditional tools (Ebba 1969).

Nevertheless, farmers in some areas have recently started using multicrop threshers and seed cleaners for threshing and seed cleaning of teff. In addition, others (like the Ethiopian Seed Enterprise) have been using combiners for harvesting and threshing of teff grains by adjusting and modifying of the drums and the seed cleaning sieves to fit to the small-seeded teff crop. Considering the difficulties entailed in teff harvesting and threshing by the smallholder farmers, the operation cannot continue to be done traditionally. It seems timely for the willing smallholder farmer to develop harvesting and threshing practices with implements for teff husbandry in Ethiopia.

Storage

Teff seeds are usually stored under ambient environmental conditions in traditional storage structures known as *gotera* or *gota* (Ebba 1969). They are also stored in farmers' houses after being packed in sacks often made of synthetic polymers. Normally teff grains can be stored for three to five years without considerable loss of viability even under traditional storage conditions, since storage pests, such as weevils, and diseases do not attack them. The only problem with the minute-size teff seeds is mechanical mixing and contamination of the pure grain at all stages of operations, starting from sowing up to the final harvesting and threshing as well as storage. The seeds can easily get dropped and missed because of their physical size.

Crop Protection (Pest Management)

Important Weeds and Their Management

Weed management has remained one of the back-breaking, labor-intensive, and time-consuming operations in teff husbandry. The major weeds of teff recorded in Ethiopia have been listed in a weed research review in Ethiopia by Fessehaie and Tadele (2001) and more recently by Zewdie and Damte (2013). Generally, annual grass weeds pose the greatest challenge because of their morphological similarity to the teff crop and their extended period of germination that is difficult to control by manual hand weeding (Fessehai and Tadele 2001). These authors, however, listed other problematic weeds in teff that include the parasitic witchweed (*Striga hermonthica* [Del.]), the introduced alien invasive weed commonly known as congress weed (*Parthenium hyterophorus* L.), field bind weed (*Convolvulus arvensis*), and other noxious weeds. The latter include weeds with the following characteristics: (1) those irritating to touch that interfere with weeding or harvesting operations, thereby increasing weeding and/or harvesting time and costs (such as *Argemone mexicana, Xanthium spinosum, X. strumarium, Oxygonum sinuatum*, and *Tribulus terristeris*); (2) those posing the biggest challenge because of their similarity to teff and extended period of germination (such as *Phalaris paradoxa* and *Setaria pumila*); (3) weeds that reduce the quality of teff grains harvested (such as *Phalaris paradoxa, Setaria pumila, Plantago lanceolata, Amaranthus* spp., *Guizotia scabra,* and *Snowdenia polystachya*); and (4) hard-to-pull-out perennial weeds (such as *Cyperus esculentus, C. rotundus*, and *Rumex bequarttii*).

While the critical period of weed completion for teff is three to four weeks and six to seven weeks postemergence of the crops, a single application of postemergence selective herbicides (such as Starane M 64 percent b EC, Derby 175 SC, Mustang, and 2,4-D Amine Salt 72 percent S) about 25 to 30 days after crop emergence has proved effective in controlling the dominant broadleaf weeds in teff, thereby giving significant yield increase. This is followed by twice hand weeding and the check with a single 2,4-D Amine Salt 72 percent SL application (Zewdie and Damte 2013). These authors also maintained that one supplementary hand weeding in addition to the single postemergence application of herbicides may be needed depending on the weed flora infestation and effectiveness of the herbicides to maximize yields.

Important Insect Pests and Their Management

More than 40 insect species have been recorded on teff. Of these, the most important, generally sporadic ones in various teff-growing areas are teff grasshopper (*Ailopus longicornis*), teff shoot fly (different species), red teff worm (*Mentaxya ignicollis*), Wello bush cricket (*Decticoides brevipennis* Ragge), termites (*Macrotermus subhyalinus* and *Odontotermus* spp.), and black teff beetle (*Erlangerius niger*) (Damte 2013).[6] In a recent review of entomological research on teff, Damte (2013) provided a list of insect species recorded on teff and further maintained that the majority of the research on teff insect pest management to date focused on the identification of appropriate insecticides to the exclusion of other management aspects such as cultural control (for example, sowing date, seed rate, fertilizer rate, teff host plant resistance), biological control (natural enemies), and ecological methods.

6 "Black teff" is an alternative name for red teff.

Important Diseases and Their Management

Teff, as compared with the other cereals, generally suffers less from disease epidemics, but the significance of diseases should not be underestimated (Amogne, Kassaye, and Bekele 2001). In a review of teff pathology research in Ethiopia, Amogne, Kassaye, and Bekele (2001) indicated that more than 24 fungal pathogens and 2 nematodes have been reported to cause diseases on teff. The authors presented a list of these diseases along with their status as either minor or major. Although most of the recorded diseases are at least sporadically economically important, the major diseases are teff rust (*Uromyces eragrostidis* Tracy), head smudge (*Heminthosporium miyakei* Nisikado), and damping-off caused by *Drechslera* spp. and *Epicoccum nigrum* Link (Eshetu 1985).

Teff rust is widely distributed in major teff-growing areas of Ethiopia. The disease, which usually appears at the post-flowering stage of the crop, was earlier reported to cause an average yield loss of 10 to 25 percent (Ebba 1969), while in more recent studies at Debre Zeit, losses were estimated at 10 to 41 percent (DZARC 1994).

Conclusion

Teff is the most important cereal in Ethiopia, and for human consumption its cultivation is almost entirely restricted to this country. This sustained cultivation of teff by Ethiopian farmers is heightened by its relative merits compared with other crops, both in husbandry and utilization aspects. The advantages of teff in farming generally relates to the broad diversity of this crop and its consequent versatility to adapt to conditions otherwise marginal for most other crops. Teff's merits also include its nutritional richness, cash crop value to farmers, and the high fodder value of its straw, as well as the preference for it in the national diet.[7]

Since 1970, a total of 33 improved teff varieties have been released to date. Of these, only 10 varieties originated from hybridization, while the rest were developed from direct mass and/or pureline selection from germplasm. Of all the varieties, 19 were released by Debre Zeit Agricultural Research Center, and the rest were released by other research centers. Nonetheless, only a

7 With progressive disappearance of pastures and grazing lands in the highlands, farmers increasingly rely on teff straw as dry- and wet-season supplemental fodder for their cows and working draft animals, especially oxen used for traction. Teff straw is the most preferred fodder relative to all the other cereals and is highly priced/valued by farmers, often collected and stored under high care.

limited number of these varieties have been adopted by farmers, and the varieties most widely grown currently include Quncho (DZ-Cr-387), Dukem (DZ-01-974), Magna (DZ-01-196), Tsedey (DZ-Cr-37), Etsub (DZ-01-3168), and Enatite (DZ-01-354).

The minute-size teff seeds require preparation of very fine, smooth, and flat seedbeds for planting. The issue of sowing methods and seed rates has in recent years been a major issue in teff husbandry. Although the recommended seed rate for the conventional hand broadcast sowing has been 25–30 kilograms per hectare, it has been recognized that the seed rates can be reduced to 7–10 kilograms per hectare. However, sowing in rows has also achieved substantial agronomic advantages in terms of facilitating subsequent weeding and harvesting operations and would enable efficient use of applied fertilizers. The use of both reduced seed rates and row sowing in practical teff husbandry calls for the provision of smallholder farmer-friendly farm implements.

Compared with most other major cereal crops, teff suffers less from epidemics of insect pests and disease. But, owing to its poor competitive ability with weeds, the management of weeds remains one of the most demanding cultural operations. Overall, teff as a localized crop of importance only in Ethiopia has remained an "orphan crop" that has survived without the help of scientific improvement endeavors, which are currently outstanding. With respect to donors, teff remained largely marginalized particularly until the mid-1990s, when national teff research and development started obtaining the sustained support of the McKnight Foundation Collaborative Crop Research Program. However, low productivity, lodging, the minute size of the seeds, and labor intensiveness of the cultural practices still remain the major threats of teff husbandry.

Finally, it is worth highlighting that over the past few years there has been an assertion that poor African countries with a number of neglected crops of localized importance should shift their farming systems to more productive crops of global significance. However, to date, this notion has no longer been an issue of debate, for it has been proven that agricultural development in these countries cannot be realized without due consideration of the neglected crops of supreme local importance like teff and "enset" in Ethiopia. Indeed, it has now been ascertained that even under the circumstances where the amount of effort and attention afforded to these crops is disproportionately low, the outcomes, as demonstrated by the remarkable achievement of developing and releasing the Quncho teff variety in 2006, are worth the investments. Hence, countries such as Ethiopia should "nurture" their neglected crops; indeed, the issue now is not whether to invest in these crops but rather how to bring about the required substantial improvements by using modern scientific techniques, including biotechnology that has been used extensively in other crops around the world.

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